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A Novel Algorithm for Estimation of QoS in Cognitive Radio Using Fuzzy Logic

[1]Nisar A. Lala, [2]Moin Uddin, [3]N.A. Sheikh

[1]Division of Agricultural Engineering, SKUAST (K) Srinagar, J & K, India

[2]Delhi Technological University, Delhi, India

[3]Department of Mathematics, National Institute of Technology Srinagar, J & K, India

Email: [1]lalanisae_ae@rediffmail.com , [2]prof_moin@yahoo.com , [3]neyaznit@yahoo.co.in

ABSTRACT

Cognitive radio is a technology initiated by many research organizations and academic institutions to raise the spectrum utilization of underutilized spectrum channels through dynamic spectrum access. Quality of service (QoS) provisioning in cognitive radio network is a challenging task due to limited and intermittent availability of the spectrum. In this paper, we have selected three critical parameters; bandwidth, signal strength and bit error rate (BER) to analyze their impact on QoS using fuzzy logic based approach. The simulated results provide the impact analysis of these selected parameters on perceived QoS and open new issues in designing protocol structure for spectrum sensing and management.

Keywords: Cognitive radio, fuzzy logic, QoS, spectrum management, spectrum sensing.

1. INTRODUCTION

As per the survey of Federal Communications Commission (FCC), the spectrum remains underutilized most of the time at a specific location and time [1]. The concept of cognitive radio was introduced by Mitola [2, 3]. According to well known definition by Haykin [4], the cognitive radio is an intelligent wireless communication system that is aware of its environment and uses the methodology of understanding-by-building to learn from the environment and adapt to statistical variations in the incoming radio frequency stimuli in real time with two primary objectives: 1) highly reliable communication whenever and wherever needed and 2) efficient utilization of radio spectrum.

Provisioning QoS in cognitive radio is a challenging and highly difficult task. It is the capability of various components, devices and service providers to ensure to satisfy minimum service requirements of an application. The QoS is a mechanism for controlling the performance, reliability and usability of a network [5]. QoS is a complex, nonlinear, multifunctional and difficult to model mathematically. QoS is defined as the collective effect of service performance, which determines the degree of satisfaction of a user of the service and ability to segment traffic or differentiate between traffic flows differently from others [6, 7]. The requirement of QoS depends upon the nature of flows (voice, data or multimedia) and the type of the networks (like mobile, adhoc, sensor and TV as well as cognitive radio). The QoS depends on multiple parameters and these parameters are imprecise and uncertain by nature. Fuzzy logic provides a better solution suitable to handle vague, imprecise and noisy information. In this paper, we have proposed fuzzy logic technique to analyze the impact of multiple parameters on the QoS of a communication channel in a cognitive radio network. Initially, fuzzy logic was applied to many control system applications [8, 9] and later on, its applications have been extended to telecommunication networks [10-12]. Fuzzy logic was applied to cellular networks for admission control in order to satisfy its QoS requirements [13] and for routing in next generation networks [14]. Fuzzy logic was applied to cognitive radio network for controlling the transmission power in order to reduce harmful interference to licensed user [15] and for cross layer optimization between medium access control layer and transport layer [16]. It was proposed for controlling the spectrum access [17, 18] and also for spectrum handoff in cognitive radio network [19-21].

The paper is organized as follows. Section 2 provides the brief introduction to cognitive radio and fuzzy logic. Section 3 proposes the fuzzy logic based framework. Section 4 presents the simulated results and the conclusion is incorporated in section 5.

2. PRELIMINARIES

A Cognitive Radio

Cognitive radio possesses the ability to sense its environment in order to find out spectrum holes or opportunity at any time and location. These spectrum holes are used by the cognitive radio opportunistically for its transmission in order to increase the utilization of the underutilized spectrum channels. The spectrum can be accessed only with the constraint of noninterference to the licensed user [22].

The main functions of the cognitive radio are:

1) Spectrum sensing: A cognitive user continuously monitors the wideband spectrum in order to find spectrum holes and arrival of licensed user with the help of different spectrum sensing techniques such as transmitter detection, interference based detection and cooperative detection. Each technique has its merits and demerits.
2) Spectrum management: Out of large number of idle channels, the CR has to select the best channel which satisfies its QoS requirements. The spectrum

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management functions can be classified as spectrum analysis and spectrum decision.

3) Spectrum mobility: Due to appearance of the licensed user on the channels occupied by the CR at that time, the CR has to change instantly its operating frequency to other idle channel. The switching to other idle channels should be seamless so that there is minimum QoS degradation of the application running on the CR.
4) Spectrum sharing: After deciding the transmitting frequency, the CR handshakes with its receiver and starts transmitting. A fair spectrum scheduling mechanism is to be devised for sharing of the spectrum with other users.

B Fuzzy Logic

The fuzzy logic deals with situations that are approximate in nature rather than exact [23]. It handles the concept of partial truth in which truth values may range between completely false and completely true. Fuzzy logic systems were developed to mimic human reasoning, and have the capability of handling non-linearity, vagueness and uncertainty without a requirement of mathematical description of a system. A fuzzy set 'A' is characterized by a membership function '$\mu_A(x)$' which takes on the value in the interval [0,1] defined over a specific universe of discourse 'U'. In a fuzzy logic, any object 'x' can be expressed by a linguistic term or variable such as 'low', 'medium' or 'high'. Each linguistic variable is associated with a term set 'T(x)', which is the set of names of linguistic values of 'x'. Each linguistic variable is a fuzzy set in a term set.

Fuzzy logic controller (FLC) can transform the linguistic control strategy based on the knowledge of an expert to an automatic control strategy. As shown in Fig. 1, FLC consists of four modules: 1) Fuzzification module 2) Fuzzy rule base module 3) Fuzzy inference engine module and 4) Defuzzification module. Fuzzification determines the degree to which the input belongs to the appropriate fuzzy set. Fuzzified inputs are used by the inference engine to evaluate the rules, with the help of fuzzy IF-THEN rules, contained in rule base. The last step is the conversion of aggregated fuzzy set to a crisp value known as defuzzification. The defuzzified value represents the action taken by the FLC. The application of fuzzy logic technique in network communication may result in better negotiation and flexible traffic contracts between users and service provider. Fuzzy logic has been successfully applied in the areas of intelligent control, data analysis, multi-criteria analysis and decision support.

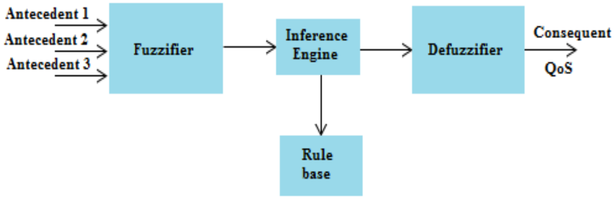


Fig. 1: Fuzzy logic system with three antecedents and a consequent.

3. PROPOSED FUZZY LOGIC BASED FRAMEWORK

The designed fuzzy logic based algorithm is used to analyze the effect of multiple parameters, such as signal strength, bandwidth and BER, of the communication channel on the QoS perceived by the secondary user in a cognitive radio network. The three input antecedents used for the system are:

1) Antecedent 1: Signal strength (dBm)
2) Antecedent 2: Bandwidth (Hz)
3) Antecedent 3: Bit error rate (BER)

and the consequence is the perceived QoS of cognitive radio.

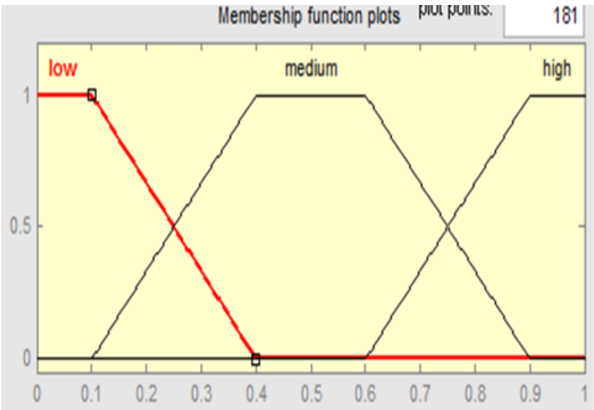
The three antecedents are characterized by the term set of three fuzzy sets, such as low, medium and high as shown in (1), defined over a specific universe of discourse

T(signal strength) = T(bandwidth) = T(BER) = {low, medium, high} (1)

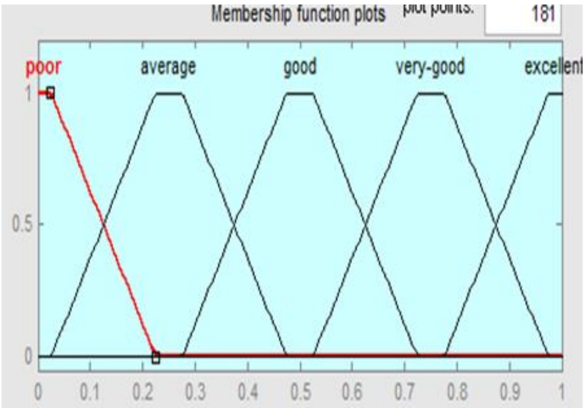
and the consequence by term set of five fuzzy sets, such as poor, average, good, very-good and excellent, as shown in (2), defined over a specific universe of discourse

T(QoS)={poor, average, good, very-good, excellent} (2)

We have used trapezoidal membership functions (MFs) for three antecedents and the consequence as shown in Figs. 2(a) and 2(b). The analysis of the algorithm has been performed over the normalized values of the antecedents



(a) Signal strength, bandwidth and BER



(b) QoS

Fig. 2: The membership functions used to represent the linguistic labels: (a) Antecedent 1 (signal strength), Antecedent 2 (bandwidth), Antecedent 3 (BER), and (b) Consequent (QoS)

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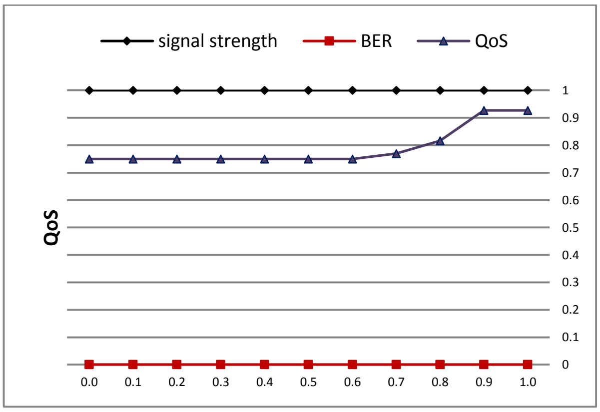
and the consequence between [0, 1]. Table 1 demonstrates the fuzzy inference rules contained in the rule base. The logic behind their definition is to realize the values of the three conflicting antecedents so as to satisfy the QoS requirement of an application. For example, rule 1 demonstrates, if the signal strength is high and bandwidth is high and BER is low then QoS will be excellent, this correspond to the situation of ideal channel conditions, where interference in the communicating channel is very low, bandwidth is plenty and very low bit error rate, the perceived quality of transmission will be very good. Also rule 27 demonstrates, if the signal strength is low and bandwidth is low and BER is high then QoS will be poor, this corresponds to the situation of high interference in the communication channel, low bandwidth and high bit error rate, the QoS requirement of the application cannot be satisfied.

Table 1: Rule base of fuzzy logic system

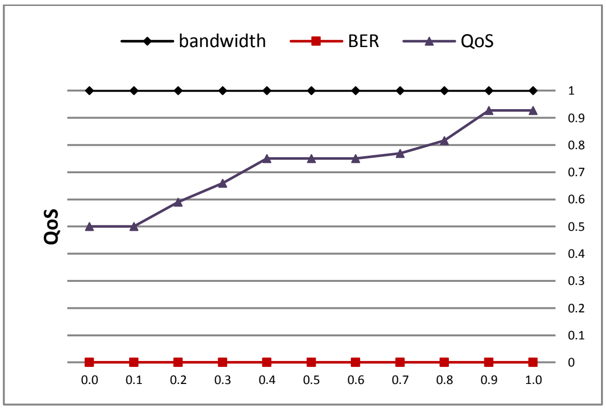
Rule #	Antecedent 1 signal strength	Antecedent 2 Bandwidth	Antecedent 3 BER	QoS
1	high	high	low	excellent
2	high	high	medium	very-good
3	high	high	high	good
4	high	medium	low	very-good
5	high	medium	medium	good
6	high	medium	high	average
7	high	low	low	good
8	high	low	medium	average
9	high	low	high	Poor
10	medium	high	low	very-good
11	medium	high	medium	good
12	medium	high	high	average
13	medium	medium	low	good
14	medium	medium	medium	average
15	medium	medium	high	poor
16	medium	low	low	average
17	medium	low	medium	poor
18	medium	low	high	poor
19	low	high	low	average
20	low	high	medium	poor
21	low	high	high	poor
22	low	medium	low	average
23	low	medium	medium	poor
24	low	medium	high	poor
25	low	low	low	poor
26	low	low	medium	poor
27	low	low	high	poor

4. SIMULATION RESULTS

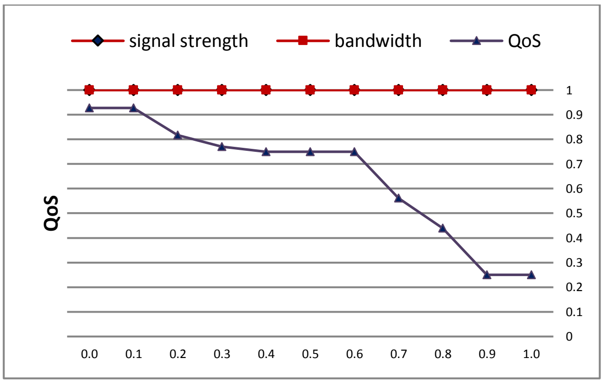
The simulation of the algorithm was done in Fuzzy logic toolbox of Matlab 7.6. Two types of simulations were performed. In the first simulation setup, QoS is analyzed as a function of one parameter while keeping other two parameters constant. Figs. 3(a), 3(b) and 3(c) show how the bandwidth, signal strength and BER influence the QoS. As can be seen from Fig. 3(a), with the increase in available bandwidth of a communication channel there is a corresponding increase in the perceived QoS of an application. As can be seen from Fig. 3(b), with the increase in signal strength of a communication channel there is also an increase in the perceived QoS of an application. As can be seen from Fig. 3(c), with the increase in BER of a communication channel there is a decrease in the perceived QoS of an application.



(a) bandwidth



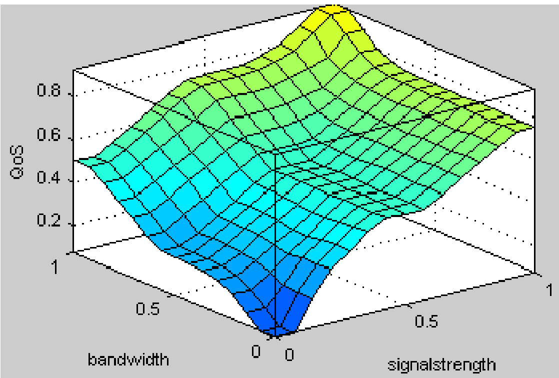
(b) signal strength



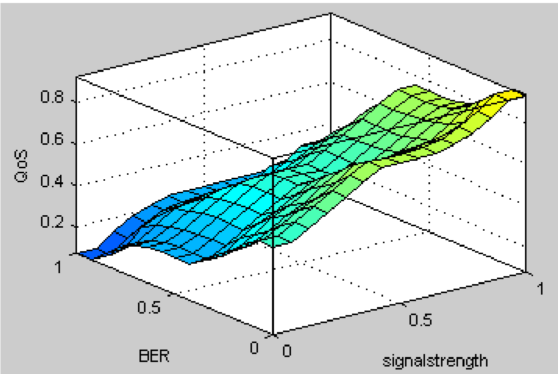
(c) BER

Fig. 3: Simulation results: (a) Effect of bandwidth on QoS at maximum signal strength (i.e.= 1) and at minimum BER (i.e.= 0) (b) Effect of signal strength on QoS at maximum bandwidth (i.e.= 1) and minimum BER (i.e.= 0) (c) Effect of BER on QoS at maximum signal strength and bandwidth (i.e.= 1).

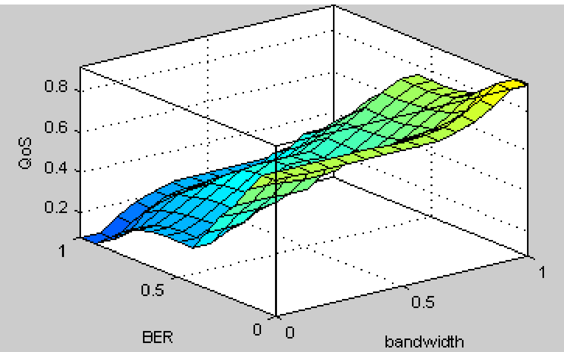
In the second simulation setup, QoS is analyzed as a function of two parameters while keeping third parameter constant. Fig. 4(a) shows simultaneous influence of bandwidth and signal strength on QoS. The results demonstrate that perceived QoS of an application increases with simultaneous increase in available bandwidth and signal strength of a communication channel and the maximum value of QoS is attained when both bandwidth and signal strength are at maximum values. Fig. 4(b) shows simultaneous influence of BER and signal strength on QoS. The results demonstrate that perceived QoS increases with increase in signal strength and decrease in BER of a communication channel and maximum value of QoS is attained when signal strength is at maximum value and BER is at minimum value. Fig. 4(c) shows simultaneous influence of bandwidth and BER on QoS. The results demonstrate that perceived QoS increases with increase in bandwidth and decrease in



(a)



(b)



(c)

Fig. 4: Simulation results show (a) Effect of bandwidth and signal strength on QoS at minimum BER (i.e.= 0) (b) Effect of BER and signal strength on QoS at maximum bandwidth (i.e. =1) (c) Effect of bandwidth and BER on QoS at maximum signal strength (i.e.=1).

BER of a communication channel and maximum value of QoS is attained when bandwidth is at maximum value and BER is at minimum value.

If the perceived QoS of a communication channel is ≥ to the required QoS of an application, the channel is selected for the communication. Otherwise, new idle channel is searched which can support the required QoS. Therefore, the proposed fuzzy based algorithm estimates the QoS of the communication channels.

5. CONCLUSION

In this paper, we have presented important characteristics of cognitive radio network and definitions of QoS in the literature. The parameters selected for analysis are heterogeneous and decisions are to be taken based on imprecise, uncertain and ill-defined information. Fuzzy logic is known to be used to deal with such situations. Fuzzy 27 IF-THEN rules were designed to help the fuzzy inference engine to take decisions based on expert knowledge. The work presented in this paper, provides the impact analysis of three parameters, namely bandwidth, signal strength and BER. The algorithm using fuzzy logic has been used to estimate the QoS of a communication channel in a cognitive radio network. This work will be extended by developing a QoS enabled admission control and routing algorithm.

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AUTHOR PROFILES

Mr. Nisar Ahmad Lala received his B. Sc. and M.Sc. in Electronics in 1990 and 1994 respectively from University of Kashmir, J & K, India. He is working as Assistant Professor in the division of Agricultural Engineering, S. K. University of Agricultural Sciences and Technology (Kashmir) Srinagar, J & K, India. He is currently pursuing Ph.D. at National Institute of Technology Srinagar, J&K, India. His research interests include Cognitive Radio Networks and Fuzzy Modeling.

Prof. Moin Uddin is a senior member, IEEE. Moin Uddin did his B.Sc. and M.Sc. Engineering in 1972 and 1978 from Aligarh Muslim University, Uttar Pradesh, India. He completed his Ph.D. in 1993 from Roorkee University, India. He has more than 30 years of experience in academics and research and is currently serving as Pro-ViceChancellor, Delhi Technological University, Delhi. Prior to this, he was Director of Dr. B R Ambedkar National Institute of Technology, Jalandhar, India. He has large number of publications in International and national Journals and fourteen research scholars have completed their Ph.D. under his guidance and five more are pursuing the same. He has designed the computer engineering curriculums of many international and national universities and institutions and is among the expert panel of these universities. Prof. Moin Uddin is a life member ISTE national society and member, board of studies, of many institutions.

Dr. Neyaz Ahmad Sheikh received his M.Sc, M.phil and Ph.D. (Applied Mathematics) in 1991, 1993 and 1996 from Aligarh Muslim University, Uttar Pradesh, India. He is working as Assistant Professor in the Department of Mathematics, National Institute of Technology Srinagar, J & K, India. He has fourteen publications in International and national Journals. His research interests include Walsh Functions and applications, Functional Analysis and some results on Wavelets.